

machine. Furthermore, even where true thermonuclear neutrons will be obtained their effects could be at first obscured by the presence of the neutrons due to collective neutrons.

### THE FUTURE OF THERMONUCLEAR POWER

The remaining difficulties appear, therefore, great enough so that it will take several more years before a machine can be constructed that produces more electric energy than it actually consumes. If that goal is reached the feasibility of controlled thermonuclear energy release will have been proven.

In a practical sense, however, the difficulties arising at that stage may be even greater than those with which we are struggling right now. It is likely that we shall be dealing with an intricate machine which is inaccessible to human hands because of radiation and on which all control and maintenance must proceed by remote control. The irradiation of materials by neutrons and gamma rays will cause the properties of these materials to change. Surfaces bombarded by the bremsstrahlung will get heated more fiercely than is the case in any portion of our present nuclear reactors. These and other difficulties are likely to make the released energy so costly that an economic exploitation of controlled thermonuclear reactions may not turn out to be possible before the end of the 20th century.

Nevertheless the ultimate goals toward which we are working are apt to be highly rewarding. Production of energy may not be the earliest practical fruit of the present extensive plasma research. Furthermore, when economic thermonuclear energy production becomes feasible we shall reap a number of important benefits.

The fuel of the thermonuclear reactors is cheap and practically inexhaustible. Thermonuclear reactors produce less dangerous radioactive materials and when once brought under control are not likely to be subject to dangerous excursions. Therefore, they can be operated more safely than fission reactors. Finally, the interaction of the hot plasma with magnetic fields opens up the way of direct production of electric energy. This may be of great practical advantage since high-temperature heat exchangers and many moving parts could be eliminated.

### PLOWSHARE

This survey should not be concluded without mentioning another way in which thermonuclear energy can be made to serve peaceful and constructive purposes. Our recent investigations have led increasingly to the expectation that thermonuclear explosions can be brought sufficiently under control to be of help in earth-moving jobs, in mining, and conceivably even in the production of energy.

Recently an underground detonation of a fission device in Nevada has demonstrated the feasibility of the confinement of the energy of the bomb. Furthermore, this experiment has shown that the bulk of the radioactive fission products was entrapped in the glass from the molten rock. The energy in this case was primarily dissipated at low temperature in vaporizing the